Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

Thursday 11 May 2017 (afternoon)

Candidate session number

2 hours 15 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[95 marks]**.

2217 – 6114

21 pages

Answer **all** questions. Write your answers in the boxes provided.

1. There are many oxides of silver with the formula Ag_xO_y. All of them decompose into their elements when heated strongly.

(a) (i) After heating 3.760 g of a silver oxide 3.275 g of silver remained. Determine the empirical formula of Ag_xO_y. [2]

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(ii) Suggest why the final mass of solid obtained by heating 3.760 g of Ag_xO_y may be greater than 3.275 g giving one design improvement for your proposed suggestion. Ignore any possible errors in the weighing procedure. [2]

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(b) Naturally occurring silver is composed of two stable isotopes, ^{107}Ag and ^{109}Ag.

The relative atomic mass of silver is 107.87. Show that isotope ^{107}Ag is more abundant. [1]

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(Question 1 continued)

(c) (i) Some oxides of period 3, such as Na_2O and P_4O_{10}, react with water. A spatula measure of each oxide was added to a separate 100 cm^3 flask containing distilled water and a few drops of bromothymol blue indicator.
The indicator is listed in section 22 of the data booklet.

Deduce the colour of the resulting solution and the chemical formula of the product formed after reaction with water for each oxide. [3]

Flask containing	Colour of solution	Product formula
Na_2O	. . . . .	. . . . .
P_4O_{10}	. . . . .	. . . . .

(ii) Explain the electrical conductivity of molten Na_2O and P_4O_{10}. [2]

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(d) Outline the model of electron configuration deduced from the hydrogen line emission spectrum (Bohr's model). [2]

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2. (a) An acidic sample of a waste solution containing $Sn^{2+}(aq)$ reacted completely with $K_2Cr_2O_7$ solution to form $Sn^{4+}(aq)$.

(i) State the oxidation half-equation. [1]

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(ii) Deduce the overall redox equation for the reaction between acidic $Sn^{2+}(aq)$ and $Cr_2O_7^{2-}(aq)$, using section 24 of the data booklet. [1]

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(iii) 13.239 g of $K_2Cr_2O_7(s)$ were dissolved in distilled water to form a 0.100 dm^3 solution. Calculate its molar concentration. [1]

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(iv) 10.0 cm^3 of the waste sample required 13.24 cm^3 of the $K_2Cr_2O_7$ solution. Calculate the molar concentration of $Sn^{2+}(aq)$ in the waste sample. [2]

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(v) Identify one organic functional group that can react with acidified $K_2Cr_2O_7(aq)$. [1]

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(Question 2 continued)

(b) (i) Corrosion of iron is similar to the processes that occur in a voltaic cell. The initial steps involve the following half-equations:

$$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$$

$$\frac{1}{2}O_2(g) + H_2O(l) + 2e^- \rightleftharpoons 2OH^-(aq)$$

Calculate $E^\ominus$, in V, for the spontaneous reaction using section 24 of the data booklet. [1]

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(ii) Calculate the Gibbs free energy, $\Delta G^\ominus$, in kJ, which is released by the corrosion of 1 mole of iron. Use section 1 of the data booklet. [2]

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(iii) Explain why iron forms many different coloured complex ions. [3]

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(c) Zinc is used to galvanize iron pipes, forming a protective coating. Outline how this process prevents corrosion of the iron pipes. [1]

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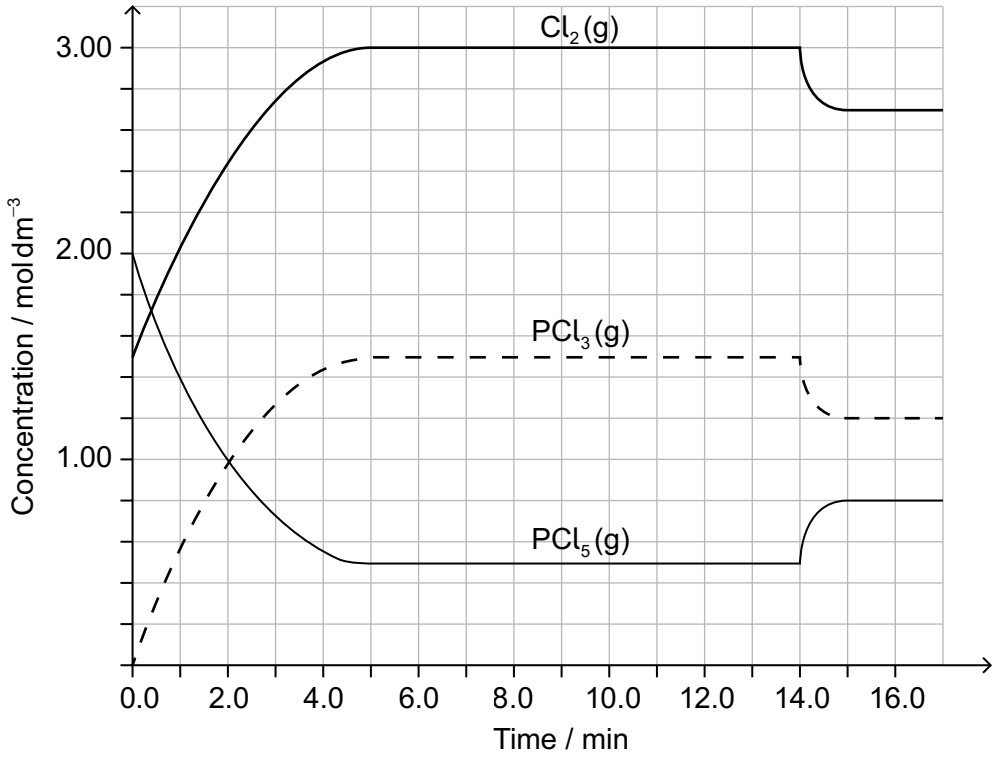
3. $PCl_5(g)$ and $Cl_2(g)$ were placed in a sealed flask and allowed to reach equilibrium at 200°C. The enthalpy change, ΔH, for the decomposition of $PCl_5(g)$ is positive.



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(a) (i) Deduce the equilibrium constant expression, K_c, for the decomposition of $PCl_5(g)$. [1]

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(ii) Deduce, giving a reason, the factor responsible for establishing the new equilibrium after 14 minutes. [2]

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(Question 3 continued)

(b) Deduce the Lewis (electron dot) structure, molecular geometry and the bond angles of PCl_3. [3]

Lewis structure:

Molecular geometry:

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Bond angles:

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4. Bonds can be formed in many ways.

(a) The landing module for the Apollo mission used rocket fuel made from a mixture of hydrazine, N_2H_4, and dinitrogen tetraoxide, N_2O_4.

$$2N_2H_4(l) + N_2O_4(l) \rightarrow 3N_2(g) + 4H_2O(g)$$

(i) State and explain the difference in bond strength between the nitrogen atoms in a hydrazine and nitrogen molecule. [2]

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(ii) State why hydrazine has a higher boiling point than dinitrogen tetraoxide. [1]

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(Question 4 continued)

(iii) Determine the oxidation state of nitrogen in the two reactants. [1]

N_2H_4:

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N_2O_4:

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(iv) Deduce, giving a reason, which species is the reducing agent. [1]

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(b) (i) Discuss the bonding in the resonance structures of ozone. [3]

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(ii) Deduce one resonance structure of ozone and the corresponding formal charges on each oxygen atom. [2]

(This question continues on the following page)

(Question 4 continued)

(c) The first six ionization energies, in $kJ\,mol^{-1}$, of an element are given below.

IE_1	IE_2	IE_3	IE_4	IE_5	IE_6
578	1816	2744	11576	14829	18375

Explain the large increase in ionization energy from IE_3 to IE_4. [2]

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(d) The equilibrium for a mixture of NO_2 and N_2O_4 gases is represented as:

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

At 100°C, the equilibrium constant, K_c, is 0.21.

(i) At a given time, the concentration of $NO_2(g)$ and $N_2O_4(g)$ were 0.52 and $0.10\,mol\,dm^{-3}$ respectively.
Deduce, showing your reasoning, if the forward or the reverse reaction is favoured at this time. [2]

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(ii) Comment on the value of ΔG when the reaction quotient equals the equilibrium constant, $Q = K$. [2]

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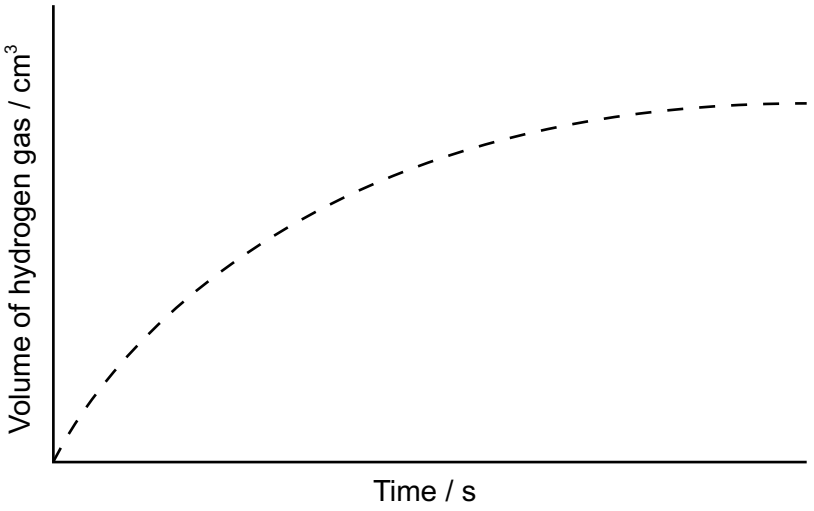
5. (a) Magnesium reacts with sulfuric acid:

$$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$$

The graph shows the results of an experiment using excess magnesium ribbon and dilute sulfuric acid.



(i) Outline why the rate of the reaction decreases with time. [1]

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(ii) Sketch, on the same graph, the expected results if the experiment were repeated using powdered magnesium, keeping its mass and all other variables unchanged. [1]

(b) Nitrogen dioxide and carbon monoxide react according to the following equation:

$$NO_2(g) + CO(g) \rightleftharpoons NO(g) + CO_2(g) \qquad \Delta H = -226\,kJ$$

Experimental data shows the reaction is second order with respect to NO_2 and zero order with respect to CO.

(i) State the rate expression for the reaction. [1]

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(This question continues on the following page)

(Question 5 continued)

(ii) The following mechanism is proposed for the reaction.

Step I $NO_2(g) + NO_2(g) \rightarrow NO(g) + NO_3(g)$

Step II $NO_3(g) + CO(g) \rightarrow NO_2(g) + CO_2(g)$

Identify the rate determining step giving your reason. [1]

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(iii) State one method that can be used to measure the rate for this reaction. [1]

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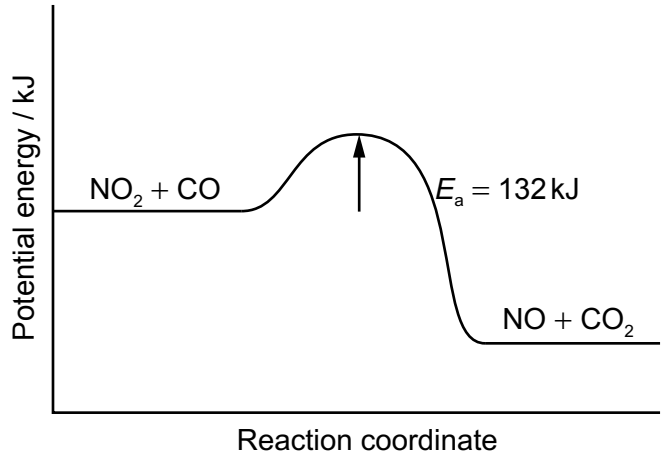
(iv) Calculate the activation energy for the reverse reaction. [1]



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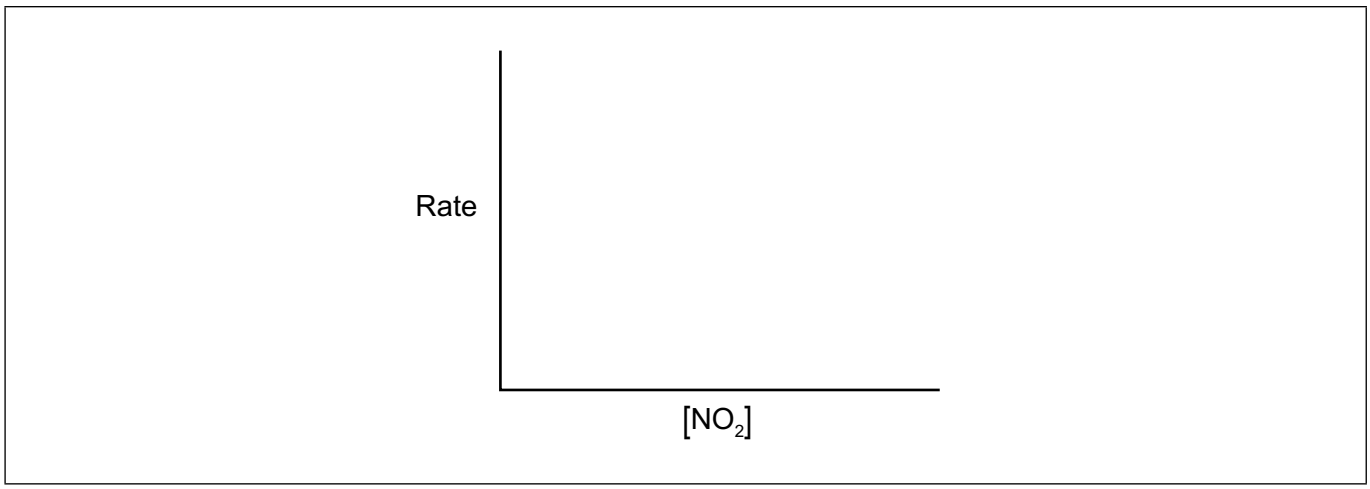
(Question 5 continued)

(v) Sketch the relationship between the rate of reaction and the concentration of NO_2. [1]



(c) The Arrhenius equation, $k = Ae^{-\frac{E_a}{RT}}$, gives the relationship between the rate constant and temperature.

State how temperature affects activation energy. [1]

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(d) State the equation for the reaction of NO_2 in the atmosphere to produce acid deposition. [1]

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6. The photochemical chlorination of methane can occur at low temperature.

(a) Using relevant equations, show the initiation and the propagation steps for this reaction. [3]

Initiation:

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Propagation:

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(b) The overall equation for monochlorination of methane is:

$$CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$$

Calculate the standard enthalpy change for the reaction, $\Delta H^{\ominus}$, using section 12 of the data booklet. [2]

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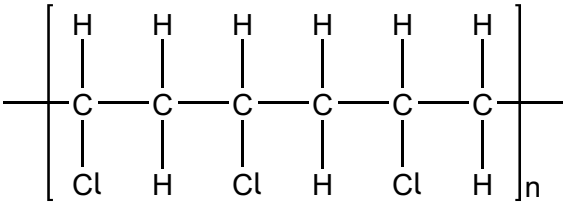
(c) Polyvinyl chloride (PVC) is a polymer with the following structure.



State the structural formula for the monomer of PVC. [1]

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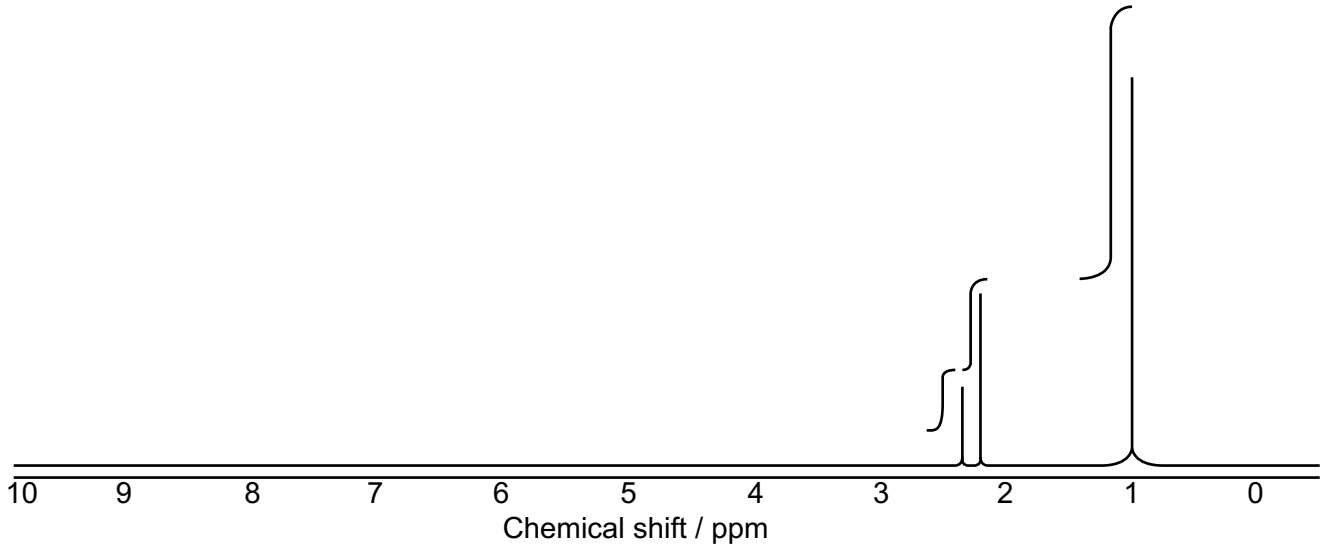
7. (a) A compound with a molecular formula $C_7H_{14}O$ produced the following high resolution ^1H NMR spectrum.



(i) Deduce what information can be obtained from the ^1H NMR spectrum. [3]

Number of hydrogen environments:

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Ratio of hydrogen environments:

. . . . . .

Splitting patterns:

. . . . . .

(ii) Identify the functional group that shows stretching at 1710 cm^{-1} in the infrared spectrum of this compound using section 26 of the data booklet and the ^1H NMR. [1]

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(Question 7 continued)

(iii) Suggest the structural formula of this compound. [2]

(b) (i) Bromine was added to hexane, hex-1-ene and benzene. Identify the compound(s) which will react with bromine in a well-lit laboratory. [1]

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(ii) Deduce the structural formula of the main organic product when hex-1-ene reacts with hydrogen bromide. [1]

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(c) (i) State the reagents and the name of the mechanism for the nitration of benzene. [2]

Reagents:

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Name of mechanism:

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(Question 7 continued)

(ii) Outline, in terms of the bonding present, why the reaction conditions of halogenation are different for alkanes and benzene. [1]

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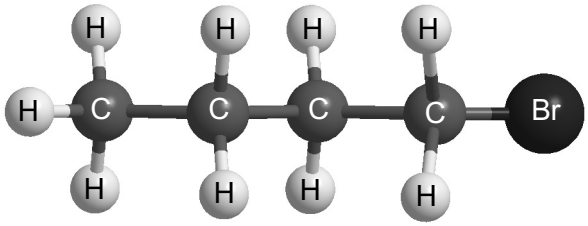
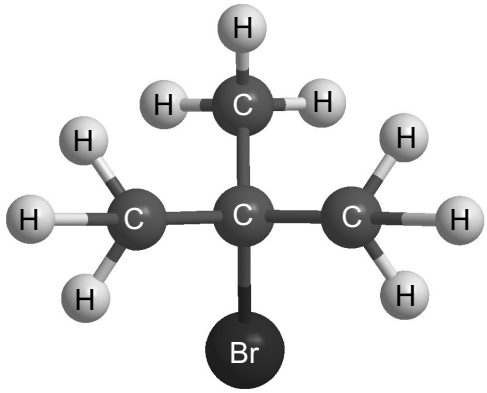
(d) Below are two isomers, A and B, with the molecular formula C_4H_9Br.



A



B

Explain the mechanism of the nucleophilic substitution reaction with NaOH(aq) for the isomer that reacts almost exclusively by an S_N2 mechanism using curly arrows to represent the movement of electron pairs. [3]

8. Soluble acids and bases ionize in water.

(a) Sodium hypochlorite ionizes in water.

$$OCl^-(aq) + H_2O(l) \rightleftharpoons OH^-(aq) + HOCl(aq)$$

(i) Identify the amphiprotic species. [1]

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(ii) Identify one conjugate acid-base pair in the reaction. [1]

Acid	Base
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(b) A solution containing 0.510 g of an unknown monoprotic acid, HA, was titrated with $0.100\,mol\,dm^{-3}$ NaOH(aq). $25.0\,cm^3$ was required to reach the equivalence point.

(i) Calculate the amount, in mol, of NaOH(aq) used. [1]

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(ii) Calculate the molar mass of the acid. [1]

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(iii) Calculate $[H^+]$ in the NaOH solution. [1]

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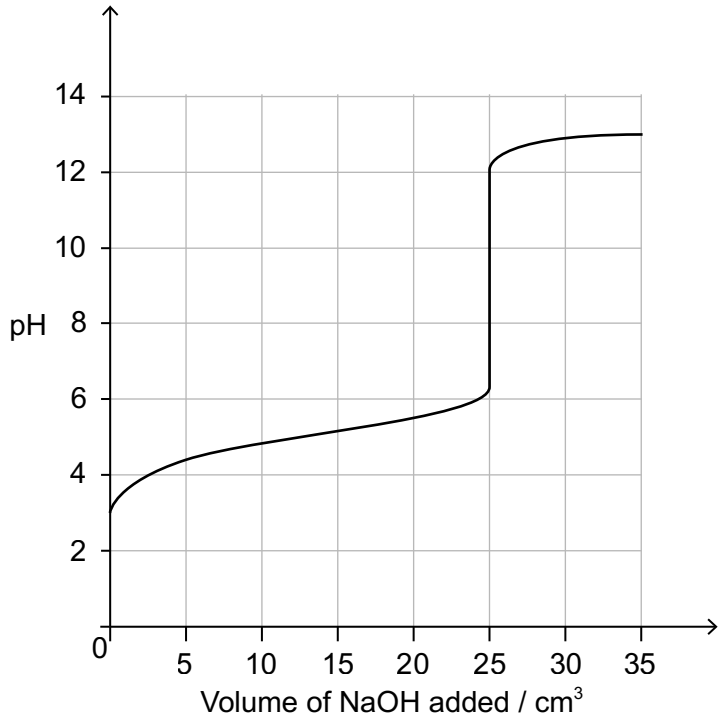
(Question 8 continued)

(iv) The following curve was obtained using a pH probe.



State, giving a reason, the strength of the acid. [1]

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(v) State a technique other than a pH titration that can be used to detect the equivalence point. [1]

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(vi) Deduce the pK_a for this acid. [1]

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(Question 8 continued)

(c) The pK_a of an anthocyanin is 4.35. Determine the pH of a $1.60 \times 10^{-3}\,\text{mol}\,\text{dm}^{-3}$ solution to two decimal places. [3]

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9. The Bombardier beetle sprays a mixture of hydroquinone and hydrogen peroxide to fight off predators. The reaction equation to produce the spray can be written as:

$$\underset{\text{hydroquinone}}{C_6H_4(OH)_2(aq)} + H_2O_2(aq) \rightarrow \underset{\text{quinone}}{C_6H_4O_2(aq)} + 2H_2O(l)$$

(a) (i) Calculate the enthalpy change, in kJ, for the spray reaction, using the data below. [2]

$C_6H_4(OH)_2(aq) \rightarrow C_6H_4O_2(aq) + H_2(g)$ $\Delta H^{\ominus} = +177.0\,kJ$

$2H_2O(l) + O_2(g) \rightarrow 2H_2O_2(aq)$ $\Delta H^{\ominus} = +189.2\,kJ$

$H_2O(l) \rightarrow H_2(g) + \frac{1}{2}O_2(g)$ $\Delta H^{\ominus} = +285.5\,kJ$

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(ii) The energy released by the reaction of one mole of hydrogen peroxide with hydroquinone is used to heat 850 cm^3 of water initially at 21.8°C. Determine the highest temperature reached by the water.

Specific heat capacity of water = 4.18 $kJ\,kg^{-1}\,K^{-1}$.

(If you did not obtain an answer to part (i), use a value of 200.0 kJ for the energy released, although this is not the correct answer.) [2]

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(Question 9 continued)

(b) (i) Hydrogenation of propene produces propane. Calculate the standard entropy change, $\Delta S^{\ominus}$, for the hydrogenation of propene. [2]

Formula	$S^{\ominus}$ / J K^{-1} mol^{-1}
$H_2(g)$	+131
$C_3H_6(g)$	+267
$C_3H_8(g)$	+270

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(ii) The standard enthalpy change, $\Delta H^{\ominus}$, for the hydrogenation of propene is $-124.4\,kJ\,mol^{-1}$. Predict the temperature above which the hydrogenation reaction is not spontaneous. [2]

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